

Intimate and Macroscopic Mixture Analysis by Linear and Nonlinear Regression. Study Case: Garnerite x Goethite and Garnerite x Asbolan

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Abstract: This paper evaluates the abundance of minerals estimate from spectral mixtures behavior, both macroscopically and microscopically (intimate). The analyzed mixture comes from a lateritic nickel deposit: pimelite, goethite and Mn laterite (*Fazenda Mine*, Niquelândia, GO). Mixture simulations were made as in laboratory, from the intimate mixture of the minerals powder followed by the radiometric mensuration, as from mathematical simulation using a linear function to describe the macroscopic mixtures. The calculation of the mineral abundance is estimated by indexes that compare morfometric values of the spectrum of the pure mineral with relationship to the spectrum of the mixture. In order to define the abundance of the mixture models was used the unmixed partial and scale coefficient. The abundance estimate in the intimate and macroscopic mixture can generate errors and should be corrected by mathematics adjustments with experimental data.

Key Words: macroscopic mixtures, intimate mixtures, lateritic nickel.

1 Spectral Mixture

Two types of spectral mixture can be distinguished: the macroscopic mixture and the intimate mixture. The macroscopic mixture considers that the probability of a photon's being spread among the representatives of a mixture is dependent only on the contribution area of each constituent specimen and not on a previous photon spread (Johnson *et al.*, 1983). This fact turns the spectral reflectance of a certain surface a linear combination of its individuals that makes its estimate easier.

In the intimate mixture, the components are randomly distributed within the field of view of an instrument and light is multiply scattered between mineral species (Singer, 1981; Mustard & Pieters, 1989). The spectral behavior of the intimate mixture is a nonlinear function of its components. Among the minerals intimate mixture methods of analysis there are physical models (Hapke 1981, 1984, 1986; Hapke & Wells, 1981, Lumme & Bowell, 1981) and empirical models (Adams, 1974; Singer, 1981; Cloutis *et al.*, 1986).

The physical models are based on the interaction of the electromagnetic energy with the mixture under study. Among the physical models the Hapke Model stands out. It is based on the bi-directional reflectance of intimate mixtures (Hapke & Wells, 1981). However the Hapke model requires multiple viewing geometries, which are not commonly obtained by current and planned imaging spectrometers (Mustard and Pieters, 1989).

The empirical models relate the measurable properties of the absorption features to the material abundance. It is specific for a certain mixture in study where a calibration is requested in laboratory with a systematic of mineral proportions (Adams, 1974; Singer, 1981; Cloutis *et al.*, 1986).

2 Methodology

For the analysis of a spectral mixture it was accomplished simulations as macroscopic mixture as of intimate mixture, generating a continuous series among the endmembers. The macroscopic mixtures were computational simulated using linear proportions. The intimate mixtures were simulated in a laboratory from the powder of the minerals mixture followed by the radiometric measurement. However in the intimate mixture, several conditions alter its final behavior such as the particle size and the rough.

For the mixture models the following indexes were calculated: angular and linear coefficients related to the linear regression (Harsanyi and Chang, 1994) and the scale coefficient (Clark & Roush, 1984). In order to evaluate the correlation interference of the pure spectra, was also calculated the similarity index Spectral Correlation Mapper (SCM) (Carvalho & Meneses, 2000). The methodology was tested for the mixtures garnerite x goethite and garnerite x typical asbolan of the lateritic Ni profile of the *Fazenda* mine (Niquelândia, GO).

3 Analysis of the Garnerite Abundance when Mixed with Goethite

The mixture of the garnerite and goethite is very common in lateritic Ni mineralization, as the macroscopic form as in the intimate one. For the calculation of garnerite abundance the feature used was 2.29 μm , regarding pimelite feature (Mg-OH) its main mineral composed.

The macroscopic mixture series is shown in **Figure 1** in 10% intervals abundance. A linear behavior of the angular and linear coefficient is observed in relation to garnerite abundance (**Figure 2**). However, the angular coefficient without the pimelite doesn't reach zero. That is due to the correlation among the spectra in analysis that is demonstrated by SCM that reaches values of 0.90 even in the absence of the mineral (**Figure 3**). The coefficient scale presents a nonlinear behavior; even so it is not so affected by the correlation of the spectra, obtaining values close to zero in the garnerite absence.

In the intimate mixtures series among the goethite and the pimelite accomplished in a laboratory a 10% intervals abundance was also used (**Figure 4**). The SCM in the pimelite absence also presents high values demonstrating a high correlation among the spectra. The coefficients have linear behavior (**Figure 5, 6, 7, and 8**).

4. Abundance of Garnierite Analysis when Mixed with Asbolan

The garnieritic facie of the mine has asbolan veins. In spite of the presence of the asbolan being restricted to a specific area, the use of that mixture is interesting to demonstrate another type of spectral mixture behavior.

Figure 9 presents the macroscopic mixtures series between the garnierite and the asbolan. The angular coefficient establishes a linear relationship that corresponds to the amount of garnierite due to the low correlation among the spectra (**Figure 10**). The coefficient scale doesn't obtain the same result.

In the intimate mixture a reduction of the mixture reflectance is observed due to the asbolan presence (**Figure 11**). Those results are consistent with previous studies of mineral assemblies mixture of opaque with not opaque (Pieters, 1973; Nash & Conel, 1974; Singer, 1981; Ribeiro *et al.*, 2000). The coefficients present a distribution according to a logarithmic function (**Figure 12**). The logarithmic function can be applied to the hyperspectral image providing a better estimate of the pimelite amount for areas.

5 Conclusion

The index values should be confirmed in a laboratory for the intimate mixture and the macroscopic mixture. In the macroscopic mixture the coefficient can present overestimation in the spectra correlation. The garnierite abundance in the mixture with the goethite was harmed due to that correlation. In the intimate mixture the indexes are also shown vulnerable mainly, when an albedo difference exists. The use of the logarithmic function presented excellent results for the mixture calibration. Other simulations for intimate mixture varying the particle size and rough are also necessary for a better process control. The quantification of intimate mixture in the spectroscopy image still presents a lot of problems, constituting a vast field for research.

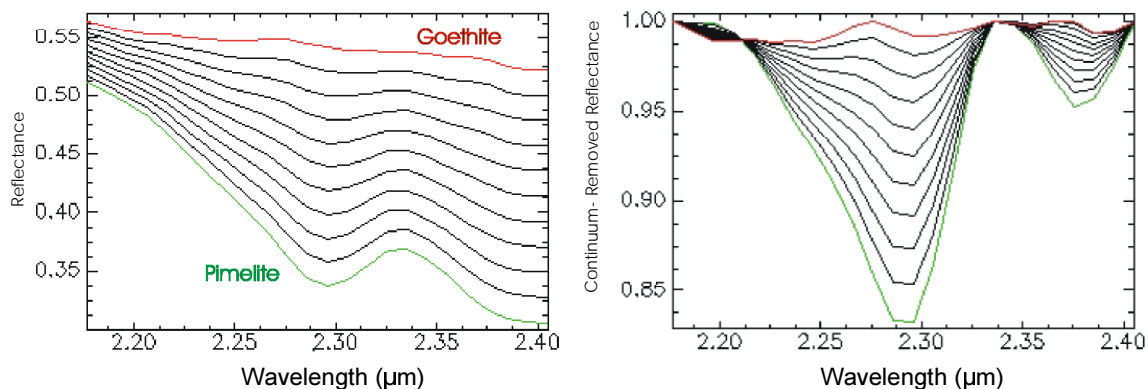


Figure 1—Simulation of the macroscopic mixtures between the pimelite and the goethite with abundance interval of 10%: a) without normalization (removal of the continuous) and b) with normalization.

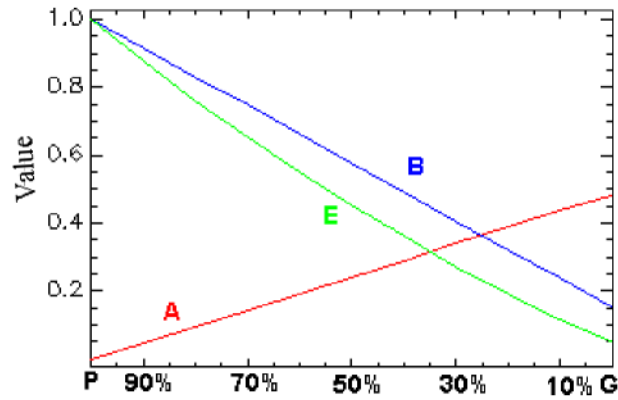


Figure 2—Angular coefficient (B), linear (A) and scale (E) behavior for the macroscopic mixtures models between the pimelite and goethite

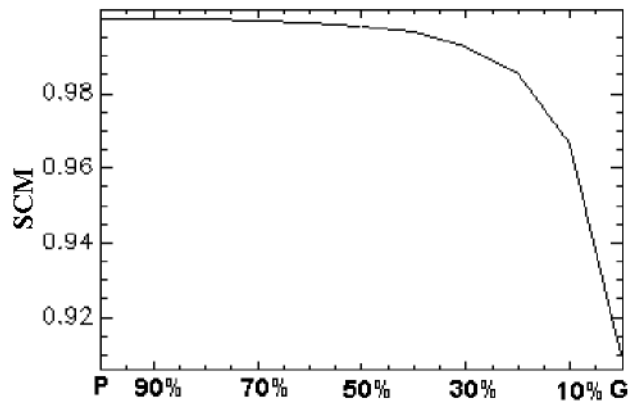


Figure 3—SCM among the pimelite and the relative curves to the macroscopic mixture among the pimelite and goethite

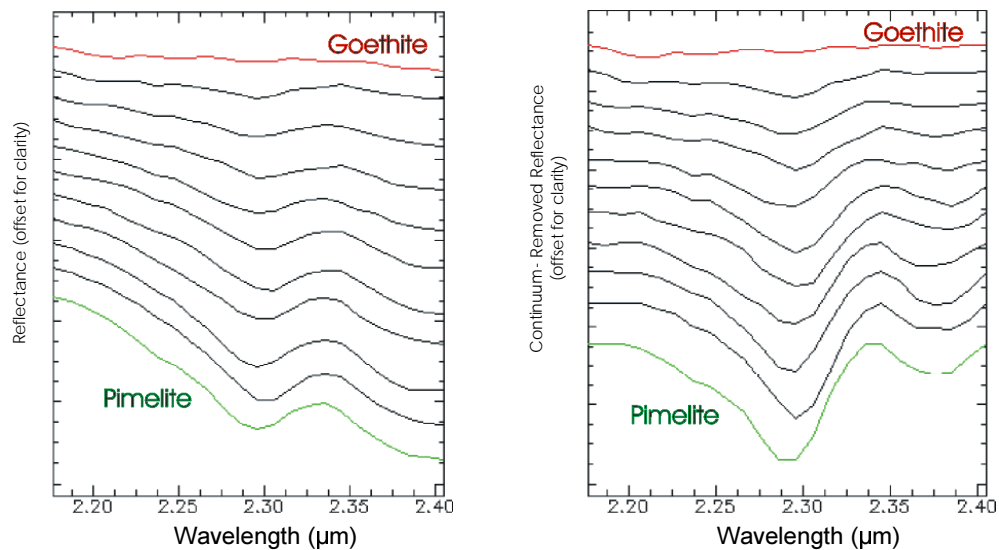


Figure 4—Simulation of intimate mixture between the pimelite and the goethite with interval abundance among the curves of 10%: a) reflectance (offset for clarity) and b) continuum remove reflectance.

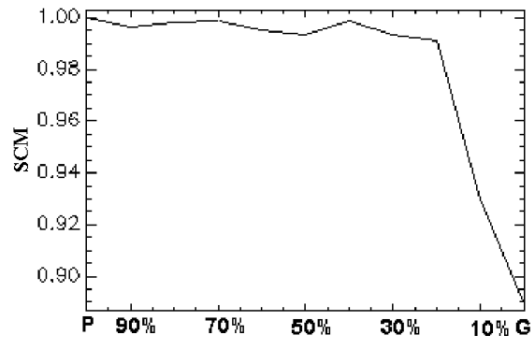


Figure 5–Values of SCM between the pimelite and the relative curves to the mixture with the goethite.

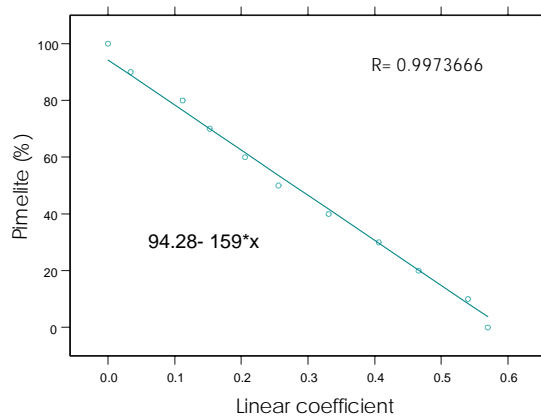


Figure 6–Linear coefficient behavior for the intimate mixture between pimelite and goethite

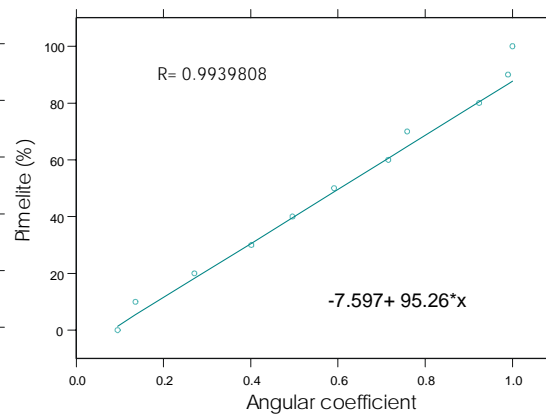


Figure 7–Angular coefficient behavior for the intimate mixture between pimelite and goethite

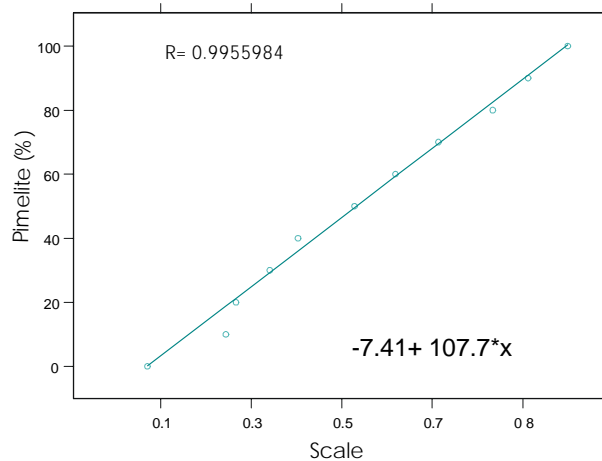


Figure 8–Coefficient scale behavior for the intimate mixture between pimelite and goethite presenting a linear distribution.

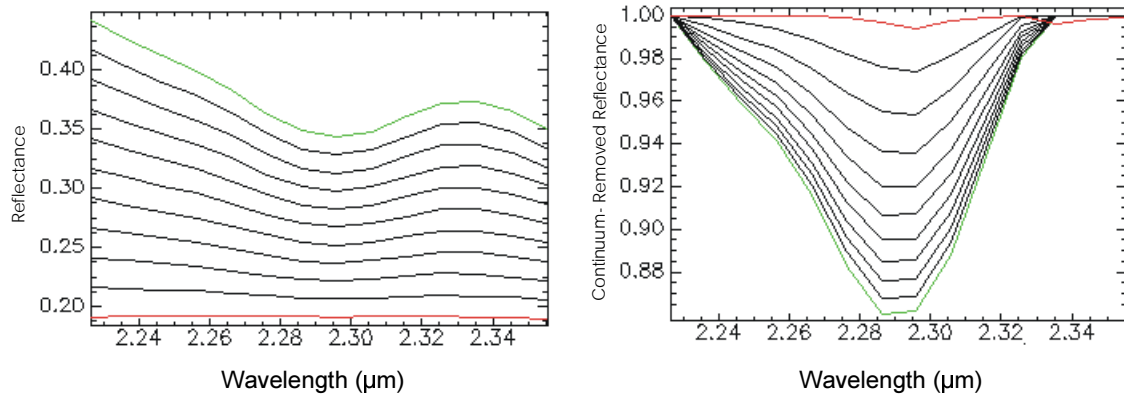


Figure 9—Macroscopic mixture simulation among the pimelite (green) and the asbolan (red), with interval of 10%: a) reflectance and b) continuum remove reflectance.

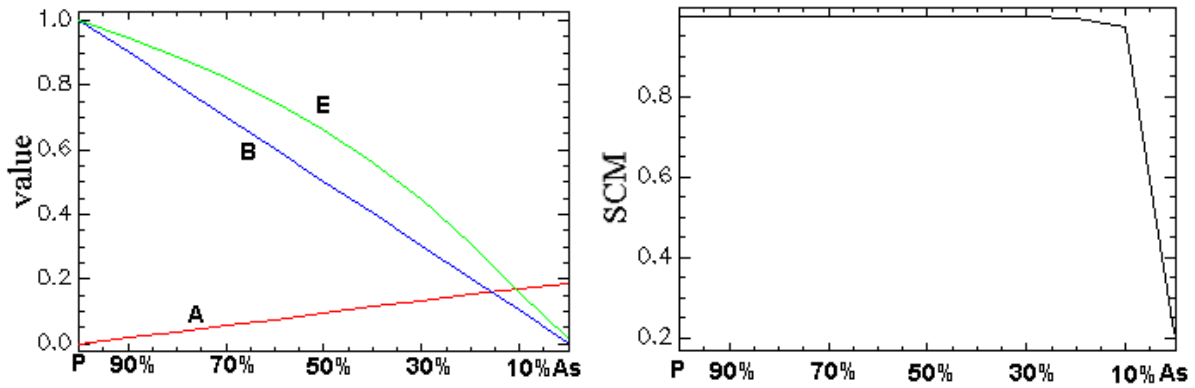


Figure 10—a) Angular coefficient (B), linear (A) and its scale (E) behavior for the macroscopic mixtures simulation between pimelite and asbolan b) SCM among pimelite and the relative curves to the macroscopic mixtures between pimelite and goethite

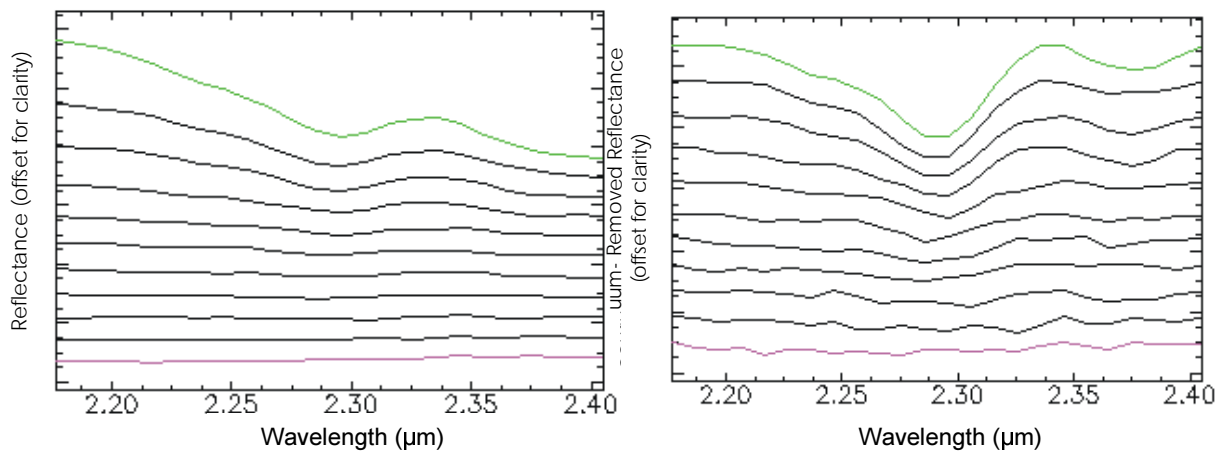


Figure 11—Intimate mixture simulation of pimelite (green) and asbolan (magenta) in interval of 10% a) reflectance (offset for clarity) and b) continuum remove reflectance.

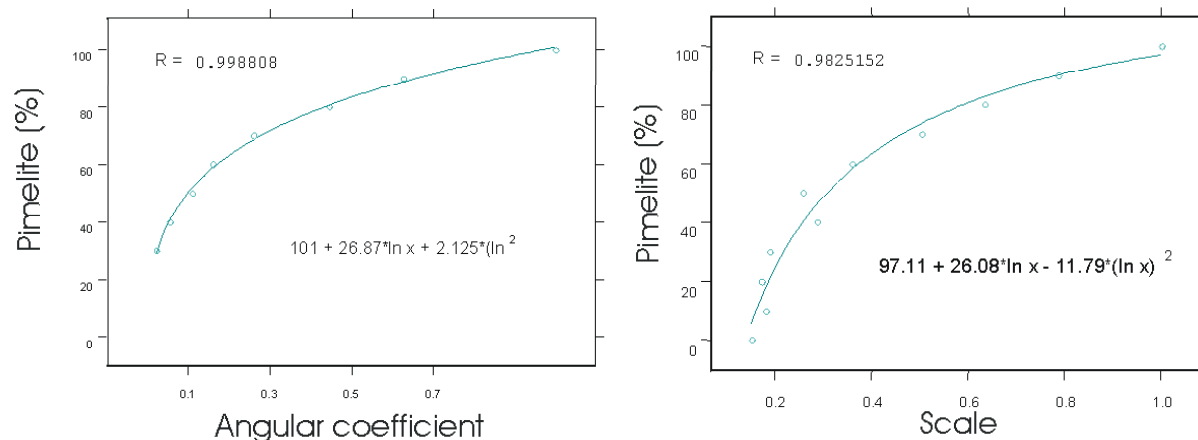


Figure 12—Logarithmic behavior of the angular coefficient, and scale for the intimate mixture between pimelite and asbolan.

References

- Adams, J. B., 1974. Visible and near-infrared diffuse reflectance: Spectra of pyroxenes as applied to remote sensing of solid objects in the solar system. *J. Geophys. Res.*, 79, 4829–4836.
- Carvalho Jr., O. A. & Meneses, P. R., 2000. Spectral Correlation Mapper (SCM): an Improving Spectral Angle Mapper, *Proceedings of the Ninth JPL Airborne Earth Science Workshop*, Jet Propulsion Laboratory, Pasadena, California, JPL Publication 00-18.
- Clark, R. N. & Lucey, P. G., 1984. Spectral properties of ice-particulate mixture and implications for remote sensing 1. Intimate Mixtures. *J. Geophys. Res.*, 89, 6341–6348
- Clark, R. N. & Roush, T. L., 1984. Reflectance Spectroscopy: Quantitative analysis techniques for remote sensing applications. *J. Geophys. Res.*, 89, 6329–6340.
- Cloutis, E. A., Gaffey, M. J., Jackowski, T. L., Reed, K. L., 1986. Calibrations of Phase Abundance, Composition, and Particle Size Distribution for Olivine—Orthopyroxene Mixtures from Reflectance Spectra, *J. Geophys. Res.*, vol. 91, NO. B11, pg. 11641–11653.
- Hapke, B., 1981. Bi-directional reflectance spectroscopy, 1, Theory, *J. Geophys. Res.*, 86, 3.039–3.054.
- Hapke, B., 1984. Bi-directional reflectance spectroscopy, 3, Correction for macroscopic roughness, *Icarus*, 59, 41–59.
- Hapke, B., 1986. Bi-directional reflectance spectroscopy, 4, The extinction coefficient and the opposition effect, *Icarus*, 67, 264–287.
- Hapke, B. & Wells, E., 1981. Bi-directional reflectance spectroscopy, 2, Experiments and observations, *J. Geophys. Res.*, 86, pp. 3.055–3.060.
- Harsanyi and Chang, 1994, Hyperspectral image classification and dimensionality reduction: An orthogonal subspace projection approach: *IEEE Trans. Geosci. and Remote Sens.*, v.32, p.779–785.

- Johnson, P. E., Smith, M. O., Taylor-George, S. & Adams, J. B., 1983. A semi-empirical method for analysis of the reflectance spectra of binary mineral mixtures, *J. Geophys. Res.*, 88, 3557–3561.
- Lumme, K. & Bowell, E., 1981. radiative transfer in the surfaces of atmosphereless bodies, I, Theory, *Astron. J.*, 86, 1.694–1.704.
- Mustard, J. F. & Pieters, C. M., 1989. Photometric phase functions of common geologic minerals and applications to quantitative analysis of mineral mixture reflectance spectra. *J. Geophys. Res.*, Vol. 94, No B10, pp. 13.619–13.634.
- Nash, D. B. and Conel, J. E., 1974. Spectral reflectance systematics for mixtures of powdered hypersthene, labradorite, and ilmenite, *J. Geophys. Res.*, 79, 161–1621.
- Pieters, C. B., 1973. Polarization in mineral absorption band, in *Planets, Stars and Nebulae Studied with Photopolarimetry*, edited by T. Gehrels, pp. 405–418, University Arizona Press, Tucson, 1973.
- Ribeiro, M. N. C., Carvalho Jr., O. A., Guimarães, E. M. & Meneses, P. R., 2000. Integral Spectral Analysis (ISA) applied to AVIRIS data for manganese mineralized laterites in São João da Aliança /GO, Brazil, *Proceedings of the Ninth JPL Airborne Earth Science Workshop*, Jet Propulsion Laboratory, Pasadena, California, JPL Publication 00-18.
- Singer, R. B., 1981. Near-infrared reflectance of mineral mixtures: Systematic combinations of pyroxenes, olivine, and iron oxides, *J. Geophys. Res.*, 86, 7967–7982.